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MECHANICAL ENGINEERING REPORT
MET-508

A METHOD FOR GUIDING EFFLUX AIR FROM A FAN-IN-WING MODEL INTO A DISCHARGE DUCT

by

U. W. SCHAUB AND R. J. RIMMER

DIVISION OF MECHANICAL ENGINEERING

OTTAWA

FEBRUARY 1970

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TEST REPORT

A METHOD FOR GUIDING EFFLUX AIR FROM A FAN-IN-WING MODEL INTO A DISCHARGE DUCT

by

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SUMMARY

A scheme is described by means of which the 12-inch fan-in-wing model in the Engine Laboratory was separated from a mechanically connected efflux-removing duct. The modifications that were introduced included a slotted bellmouth inlet, which served as a catch-flow entrance below the air gap, and a diffuser at the exit of the ducting system, which corrected the static pressure level in the duct for transmission of the full efflux flow.

The modifications were intended to facilitate mechanical isolation of the model so that direct lift measurements could be made while the efflux air was removed with essentially zero ground effect.

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A METHOD FOR GUIDING EFFLUX AIR FROM A FAN-IN-WING MODEL INTO A DISCHARGE DUCT

1.0 INTRODUCTION

A few years ago No. 6 Test Cell of the Engine Laboratory was converted into a mechanical check-out test facility for the 12-inch fan-in-wing model. Later, this facility was adapted and used to measure noise generated by the same fan. The modification made at that time comprised the erection of a large box-like enclosure constructed from 2-in thick polyurethane foam panels wired to a light angle-section steel frame. The fan efflux air was expelled to the outside of this chamber by means of an appropriate 12-in diameter ducting system and inlet air was admitted through a louvered section in one wall.

Aerodynamic testing of the same model in the 10-ft × 20-ft wind tunnel had demonstrated that test data at zero and low tunnel velocities were unreliable because of tunnel constraints. These tunnel constraints resulted in the re-ingestion of efflux air, as evidenced by persistent temperature rises in the test section, scatter in the tunnel balance data, and a general roughness of fan operation as tunnel speed was reduced. Consequently, it became evident that satisfactory zero forward speed data had not been obtained. It was also not possible to compensate for tunnel interference problems by means of corrections to the data. Since it was highly desirable to have good zero forward speed data in the general fan-in-wing program, it was decided to attempt to devise a simple test set-up that would be free from ground interference problems. The existing anechoic chamber installation already possessed all the necessary facilities to run the model, except that the fan efflux duct was mechanically connected to the wing. The possibility of measuring lift depended on several questions. Firstly, could the mechanical duct connection be eliminated while the feature of removing the efflux air smoothly and steadily was retained? Secondly, would it be possible to establish proper boundary conditions (ambient pressure) at the fan exit? Thirdly, could efflux air be removed without secondary induction or spillage so that neither an unrepresentative wing underside surface pressure distribution (ground effect), nor re-ingestion of efflux air in the fan intake would occur?

The short experimental program described involved an optimization of a configuration that ultimately satisfied the above requirements.

2.0 ANECHOIC CHAMBER INSTALLATION

The installation of the wing model for fan noise investigations is illustrated in Figure 1.

The chamber dimensions were:

Length	20 ft
Breadth	14 ft
Height	11 ft

with the wing centerline located 3 ft 4 in from the floor of the chamber and the fan axis 11 ft from the front of the chamber. Fan intake air entered the chamber through angled panels at the upper forward section. The fan efflux was expelled to the outside through a rigidly fixed 12-in diameter duct. A sliding joint attached to the underside of the wing provided the connection to the efflux duct.

3.0 MODIFIED EFFLUX DUCTING ARRANGEMENT

One way of achieving mechanical separation between the wing and the duct was simply to cut the existing duct. The requirement of flow across this air gap was recognized as being identical with that for an open-section closed-circuit wind tunnel - ambient pressure at the air gap and capture of the free jet. The concept of capturing the free jet by means of a "vented" secondary inlet has been used to great advantage in Germany, but suitable design specifications were not available.

The efflux ducting immediately below the wing was disconnected and a short length of duct removed. A vented secondary inlet was installed on the remaining vertical duct.

The optimum flow condition to be achieved was one with minimum flow spillage and induction - that is, with preservation of the efflux mass flow. Since ducting systems always introduce losses, the static pressure in the duct system would have to be higher at the secondary inlet than at the pipe exit. This condition was clearly unacceptable as far as the model was concerned. Consequently, some static pressure recovery was necessary in the duct system, and, since most of the ducting was already in place from the fan noise investigations, a conical diffuser was added to the end of the ducting system. Early running indicated that the diffuser tended to suffer from transient separation, so a short section of parallel duct was added to the delivery side of the diffuser.

Figure 2 shows the modification to the fan efflux ducting. The vented secondary inlet consisted of an existing fan inlet bellmouth of "trumpet" design (the lip contour being one-quarter ellipse of 2:1 ratio, with its major axis parallel to the inlet axis; see Detail 1). A 1-in high circumferential fence was attached to the upper surface of the secondary inlet at approximately $8\frac{1}{2}$-in radius (see Detail 2). A 1-in annular venting gap separated the secondary inlet from the vertical duct (see Detail 3). The gap inlet edge of the vertical duct was flared with a $\frac{1}{2}$-in radius in order to cope with a possible small alignment discrepancy between the vertical duct and secondary inlet discharge (± 1/16 in) without compromising the aerodynamic performance of the slot (see Detail 4).

4.0 PRESSURE MEASUREMENT

Figure 3 shows the location of the static pressure taps and pitot probes that were used for evaluating quantitatively the performance of the secondary inlet in capturing the free jet flow. The wing underside static pressure taps are shown in Figure 3, Items 1 and 2. One static tap was located in the parallel wall section of the secondary inlet (see Item 3). Another static tap was located as shown in Item 4 in the vertical duct below the venting slot. The horizontal duct was instrumented with four static taps ganged for single read-out (Item 5) and four pitot probes, also ganged (see Item 6).

5.0 TEST PROCEDURE

Preliminary observations of the flow in the vicinity of the fan efflux and fan efflux ducting were aided by smoke flow-visualization. This technique was particularly useful in low velocity regions where other indications were less meaningful. An array of smoke nozzles mixing externally sulphur dioxide and ammonia gas was used for this purpose (Ref. 1). The nozzles were distributed around the outside diameter of the secondary inlet fence, and around the vertical duct 3 in below the venting gap.

Surface pressures (Fig. 3 and Table 1) were monitored to verify the visual observations. Dimension A in Figure 2 was varied until the optimum position between the underwing surface and the secondary inlet was achieved. The criteria for the optimum position were the persistency of random low-speed smoke movement (in the neighbourhood of the secondary inlet, its venting slot, and beneath the wing near the fan exit) and low-gauge pressure readings at the wing underside.

6.0 OBSERVATIONS AND DISCUSSIONS

6.1 Modified Ducting with Fan Efflux Skirt

A preliminary investigation of the flow in the vicinity of the fan efflux and modified efflux ducting was carried out with the 3-in long skirt attached to the underside of the wing (this had been used as a sliding joint for the attached duct installation). Smoke visualization in the secondary inlet area (Fig. 4) indicated some spillage around the annular venting gap, caused by a slight misalignment of the secondary bellmouth and vertical duct. The flow across the air gap during this condition and all others tried was very steady. The fitting of a $\frac{1}{2}$-in flared radius on the gap edge of the vertical down pipe eliminated the leakage. Some low velocity spillage occurred also towards the trailing edge of the wing on the rear portion of the secondary inlet. This was stopped by the addition of the annular fence to the top surface of the secondary inlet. Although optimum flow conditions were obtained with this arrangement, removal of the skirt was considered necessary for an adequate model simulation. All subsequent tests were conducted without the skirt, as is shown in Figure 5.

6.2 Modified Ducting with Fan Skirt Removed

Pressures were not recorded for air gap distances (Dimension A, Fig. 2) exceeding $6\frac{1}{2}$ in, as smoke flow observations indicated that optimum flow conditions had not been obtained (though the flow was entirely steady). Such large gap distances usually resulted in considerable flow spillage and consequently in re-ingestion of the efflux air. The gap distance was reduced in steps of 1 in to $4\frac{1}{2}$ in and the flow spillage stopped when a gap distance of $5\frac{1}{2}$ in was reached. A detailed survey with a separate smoke probe at a fan speed of 7700 rpm revealed that an optimum geometric setting had been achieved for the gap distance $4\frac{1}{2}$ and $5\frac{1}{2}$ in. However, as higher fan speeds were anticipated, and the possibility of a "suck-down" was to be avoided, the $5\frac{1}{2}$-in dimension was chosen as the final gap dimension. The adequacy of this dimension in satisfying the requirements of acceptable gap flow was tested and confirmed for fan speeds up to 13,400 rpm. Subsequent recordings of surface pressures (Table 1) confirmed the conclusions reached by means of the smoke studies about the efflux flow field. As the throat pressure of the secondary inlet did not show a continuous trend with fan speed, it was resolved that acceptably low surface pressures* be the sole

---

* If it is specified that errors in lift measurement due to hardware constraints are not to exceed 2 lb, then it is implied that water gauge readings of only 0.05 in or less can be tolerated on the underside of the wing near the fan exit.

pressure criterion. The pressure recorded for the $5\frac{1}{2}$-in gap distance was taken as adequate confirmation of the visual observations.

7.0 CONCLUSIONS

1. Satisfactory separation of the wing from the efflux ducting was achieved through the use of a secondary venting inlet downstream of an air gap.
2. The air gap flow was found to be both smooth and steady.
3. The air gap distance was optimized for the particular vented secondary inlet, with the result that very nearly ambient pressure was achieved at the fan exit, ground effect at the wing underside was negligibly small, and efflux air re-ingestion was totally absent.
4. A minimum of spillage and induction at the secondary inlet was the result of careful air gap optimization and static pressure balance in the efflux ducting system.

8.0 REFERENCE

1. Fowler, H. S. — A Smoke Generator for Use in Wing Tunnels. NRC, DME Test Report MET-452, National Research Council of Canada, August 1964.

TABLE 1

TEST DATA

Fan rpm	13,300	13,300	7,700	13,400
Cell Static	- 0.03 RA	- 0.05 RA	- 0.02 RA	- 0.04 RA
Underside Wing Static No. 1	- 0.02 RC	- 0.05 RC	- 0.02 RC	- 0.05 RC
Underside Wing Static No. 2	- 0.05 RC	- 0.05 RC	- 0.02 RC	- 0.04 RC
Secondary Inlet Static No. 3	- 0.3 RA	- 0.95 to - 1.4 RC	- 0.7 to - 1.0 RC	- 0.8 to - 1.0 RC
Vertical Duct Static No. 4	+ 7.0 RA	+ 6.0 RA	+ 0.6 RA	+ 6.75 RA
Horizontal Duct Static No. 5	-31.5 RA	-33.5 RA	-12.0 RA	-33.0 RA
Horizontal Duct Static No. 6	+14.0 RA	+15.5 RA	+ 5.0 RA	+15.0 RA
Dimension A Fig. 2	6.5 in	4.5 in	5.5 in	5.5 in

All Pressures in Inches SG = 1.00

Test Data Pressure Reference Figure 3

RA = Relative to Ambient

RC = Relative to Cell

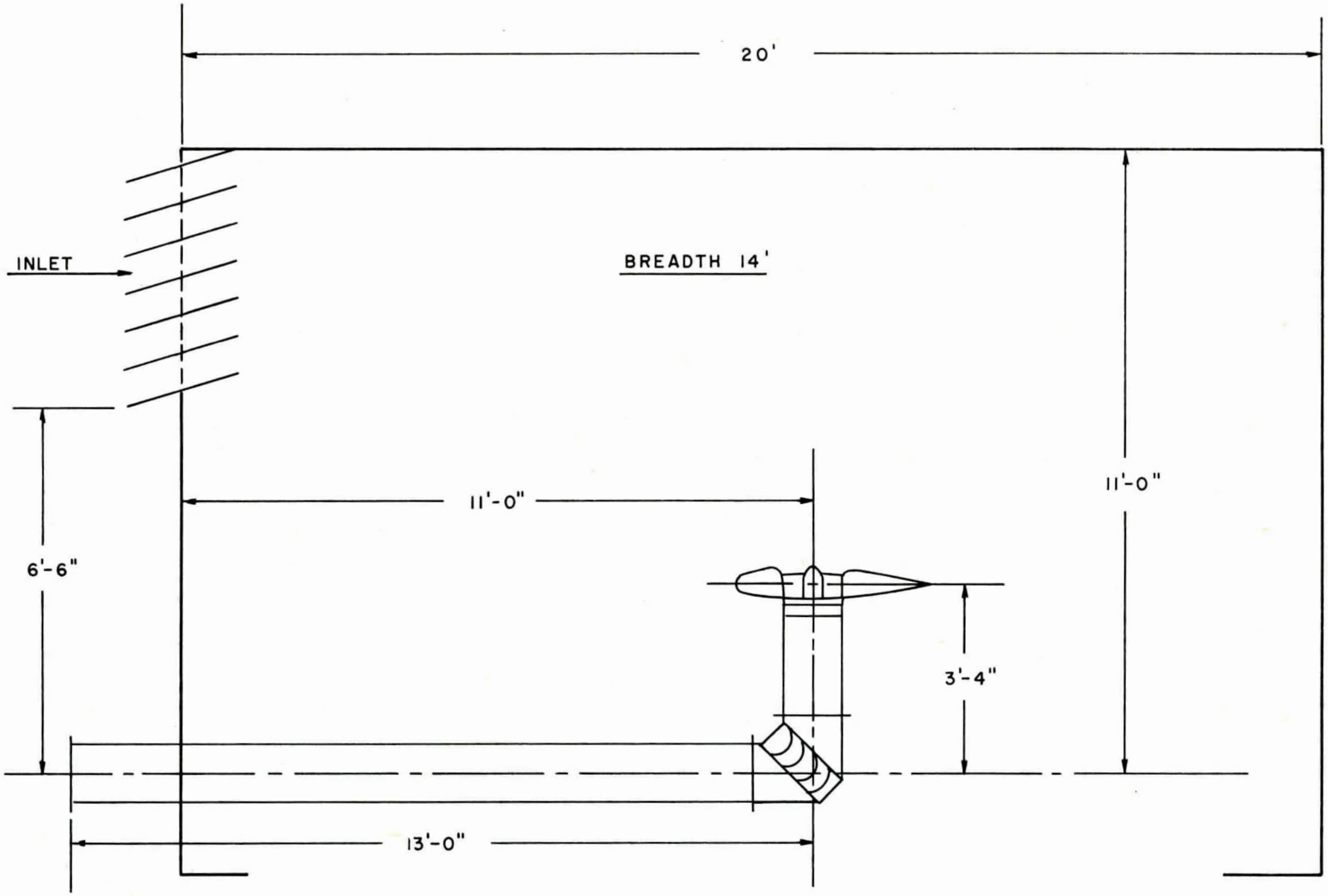

FIG. 1: ANECHOIC CHAMBER

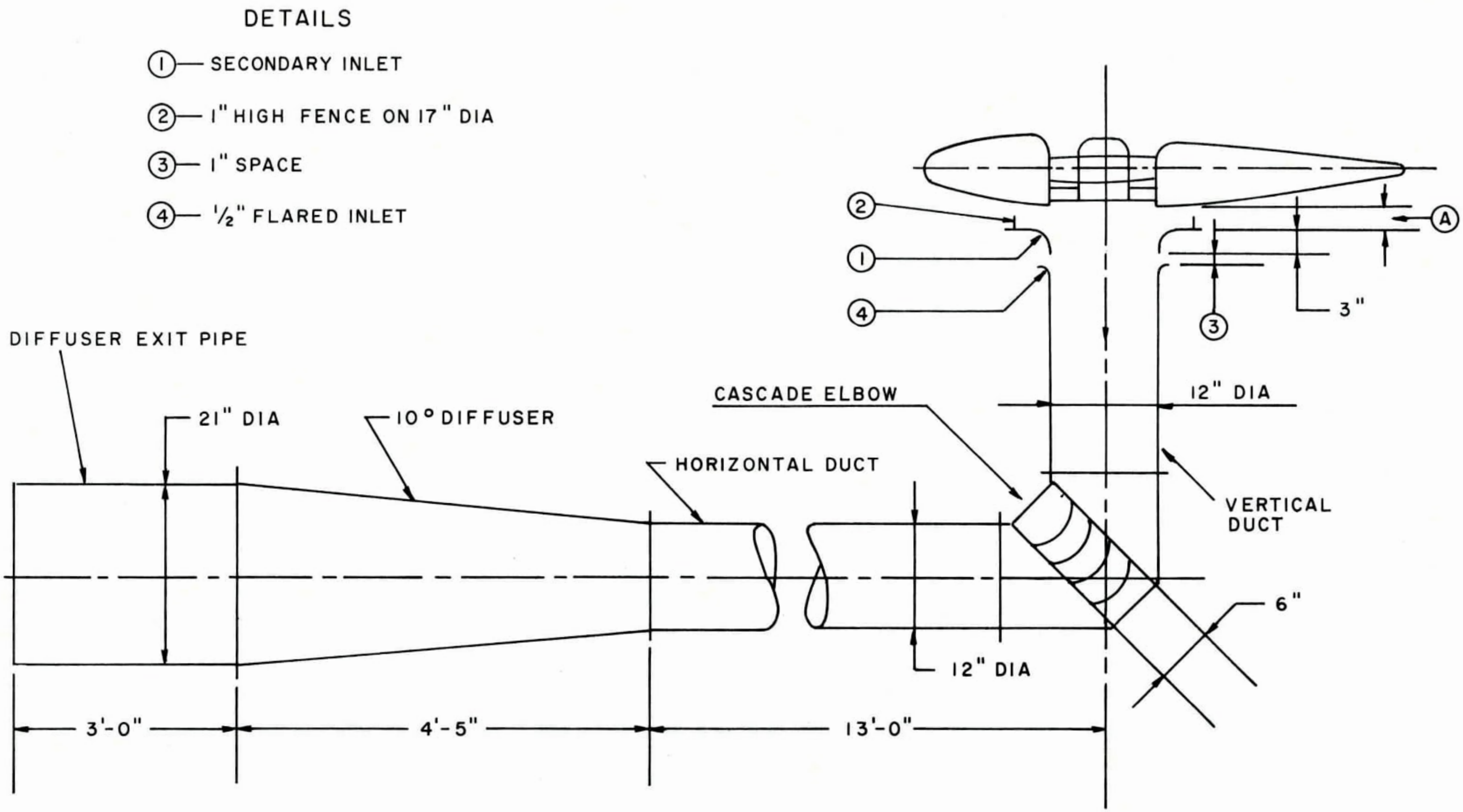

FIG. 2: MODIFIED EFFLUX DUCTING

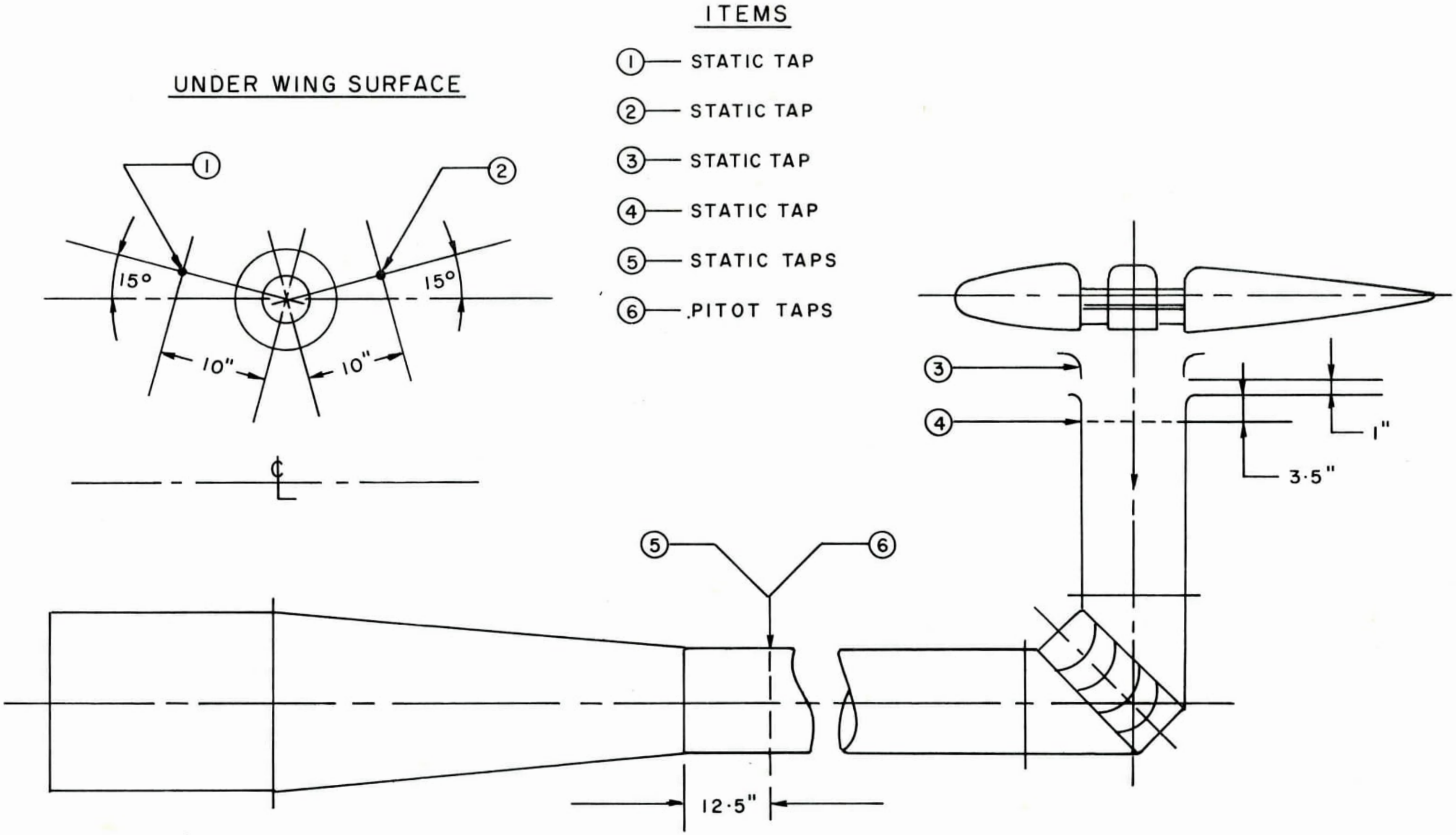

FIG. 3: DISTRIBUTION OF PRESSURE TAPS

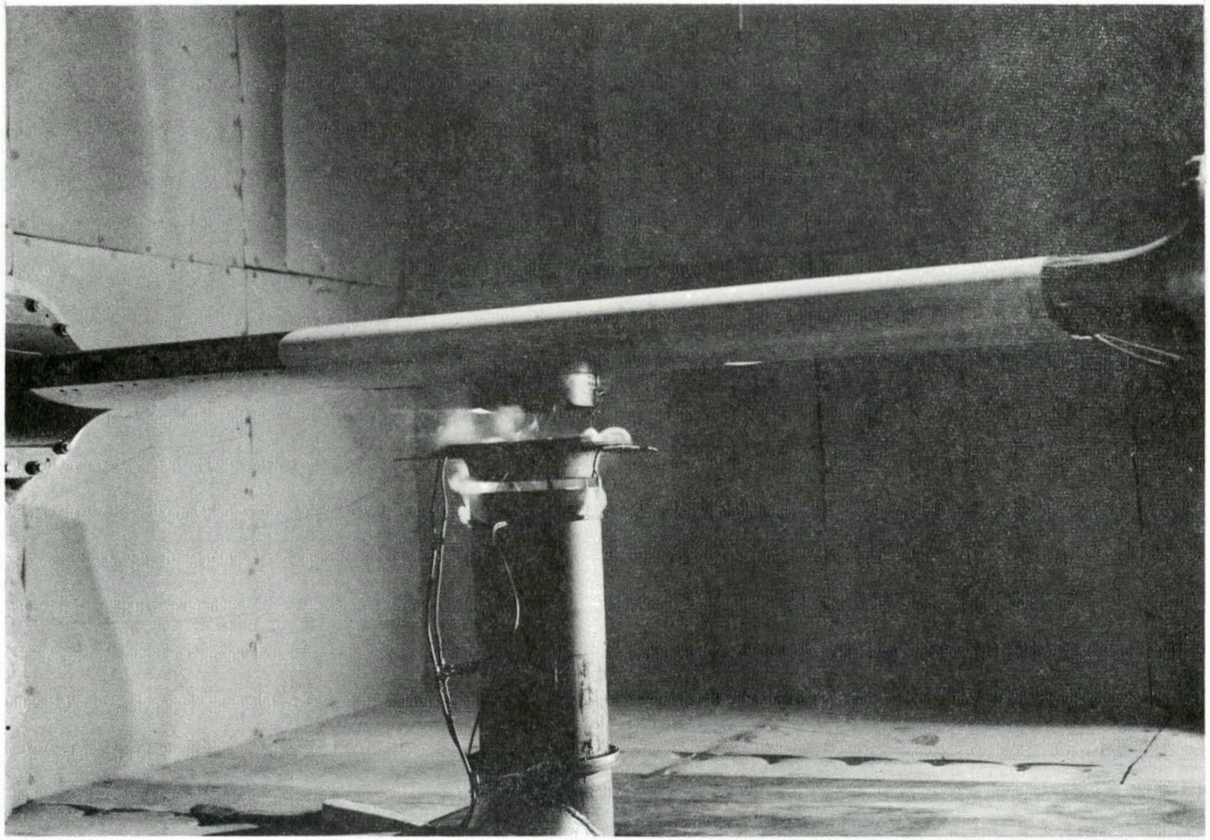

FIG. 4: SMOKE VISUALIZATION WITH EFFLUX SKIRT

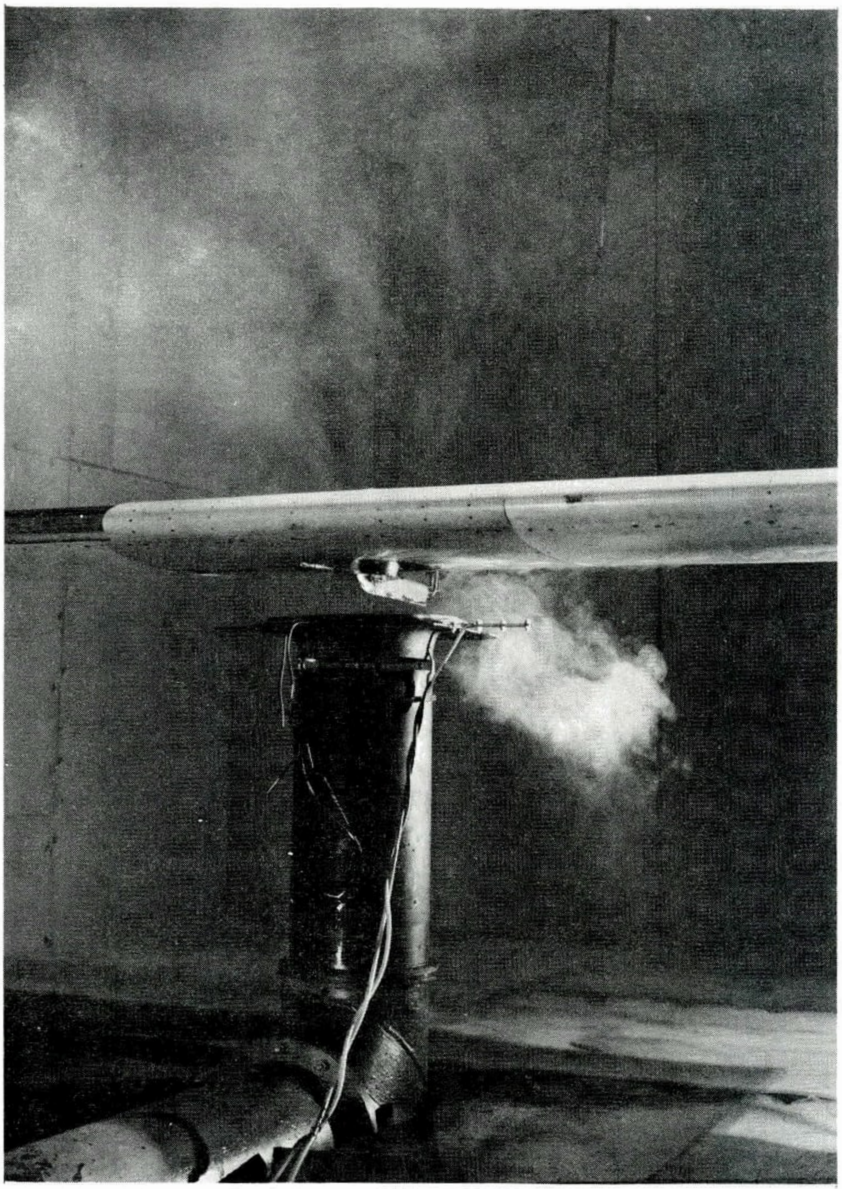

FIG. 5: SMOKE VISUALIZATION WITH SKIRT REMOVED INDICATING LOW VELOCITY SMOKE ON THE UNDER-WING SURFACE AND GENERAL INFLOW PATTERN TO THE FAN

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UNCLASSIFIED

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